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The Practical Application of Error Analysis and Safety Modelling in Air Traffic Management

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Abstract

This paper describes the programme of work being conducted by National Air Traffic Services Ltd. (NATS) and Det Norske Veritas (DNV) to apply Human Error Identification (HEI) techniques and safety modelling to the maintenance of safety within Air Traffic Management (ATM). It describes the development of an HEI tool, which provides NATS with the means to analyse human errors associated with incidents and to predict potential errors associated with future systems. This has helped to determine safeguards to defend the air traffic system against human error. A Safety Model of the ATM system has supported these activities, acting as a high-level risk communication tool. TRACEr and the safety model have been used synergistically, with results of TRACEr analyses populating the ATM Safety Model in order to track trends, define requirements for future research, and identify weaknesses in current and future systems that require the development of additional safety nets for NATS.

Introduction

Incidents in ATM are rare, but historical evidence suggests that when they do occur, human error plays a leading role. This is not surprising considering the human-centred nature of ATM, with the Air Traffic Controller to detect and resolve potential conflicts. The task of controlling air traffic is also heavily reliant on VHF radio communications to pass instructions to pilots and to receive information on aircraft intentions and status from pilots. Acting on instructions in a timely and effective manner is then the responsibility of the pilot, who in non-routine situations is reliant on their airmanship skills.

The growth of air travel is well documented in the media and literature, with passenger air transport, in particular, becoming more affordable and convenient. This has resulted in a growth in air traffic movements, which is set to continue; air traffic in the UK is expected to double over the next 15 years. This general pattern of growth makes increasing demands on the Air Traffic Control Officers (ATCOs) who are responsible for flight safety. Errors made by ATCOs can result in incidents whereby prescribed aircraft separation standards are contravened. To reduce the number of incidents that occur, and to improve the orderly and expeditious flow of air traffic, new technology, procedures, and training systems are being implemented. Such new systems are designed to increase the number of aircraft that can be handled, simplify the ATC task and improve the performance of the ATCO. However, new systems will inevitably change the nature of the ATC task, and therefore may introduce new problems. For instance, a new procedure may contradict an old procedure, and thus require a large amount of re-training. Even with extensive re-training, it is human nature to revert to the most familiar means of achieving a goal when placed under pressure. Therefore, with the introduction of new procedures, errors are still likely to occur, particularly when there is pressure on the controller to resolve a conflict between two or more aircraft. Human Error Identification (HEI) offers an approach to both learning from incidents and predict potential errors before they arise in operational systems.
NATS and the airlines are working hard to ensure that the part played by human error in air transport incidents is understood, the trends tracked, and lessons learned from each incident. In order to do this effectively, techniques for the analysis of human error in incidents need to be applied to the data pertaining to each incident. A method of analysing trends and determining how these trends will be tackled by future systems needs to be applied, so that we can detect problems with our existing safety nets and ensure that these problems are addressed.

This paper describes the approach taken by NATS to analyse errors and use this information to recommend measures that will reduce errors and to bolster our defences against the effects of these errors. This paper describes the application of Human Error Identification (HEI) to the analysis incident data and determine the types of errors which form part of these incidents, and their underlying causes. This paper also describes how the results of such analyses have been used to track the occurrence of such errors in order to evaluate the effectiveness of existing safety nets, and to determine the requirements for future safety nets.

Using Human Error Identification in ATM

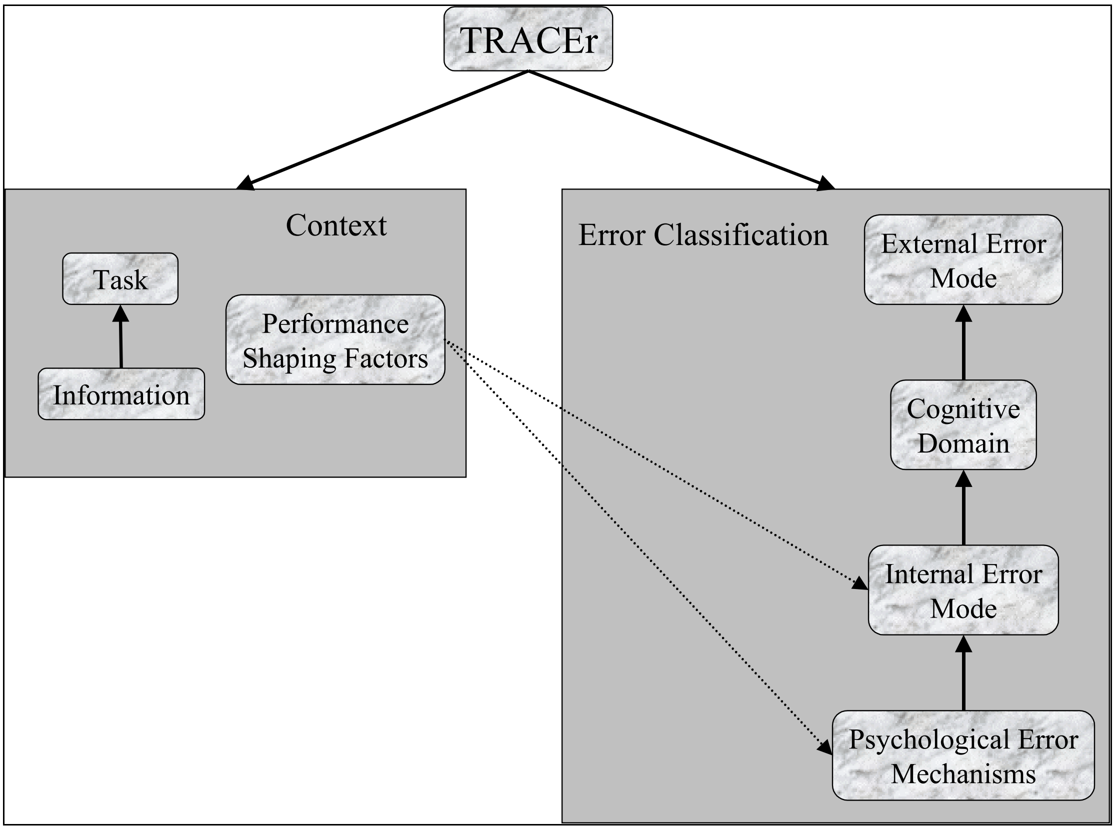
The need to examine human errors that have occurred in incidents and that could occur with the introduction of new systems points to a need for an approach that is both forward- and backward-looking, using the same basic framework. The advantages of such a technique are numerous. Perhaps the biggest advantage is that those involved in operation, training, technology development, and research can 'talk the same language' in terms of human error, thus facilitating communication and co-ordination. For example, information on human error can be fed to training personnel from both operations (current errors) and system development (potential errors). Those involved in the development of new technology can benefit from information regarding incidents that is compatible with predictions made regarding potential errors.

Few such 'bi-directional' approaches were identified in the literature. Most techniques have been used either for incident and accident analysis, or for error prediction, but few have been used extensively for both purposes. Furthermore, no such dualistic techniques were identified that have been used in the air traffic control environment. This pointed to a need to develop a new technique, which learned from the theories, techniques and frameworks already available, but was adapted for use in a development and operational environment in ATM.

This section outlines an approach developed by National Air Traffic Services Ltd. to classify errors that have occurred in incidents, and to predict potential errors associated with new systems. This system is called TRACEr - Technique for the Retrospective and Predictive Analysis of Cognitive Errors in ATM.

TRACEr was developed from a number of sources, including a review of the human error, HEI and ATM literature, incident analysis spanning several years, a number of large-scale real-time simulations, controller interviews and reviews, and predictive studies for new technology and procedures (e.g. Shorrock, 1999; Shorrock, and Kirwan, 1999; Evans *et al.*, 1999; Shorrock, *et al.*, 2000a&b; Shorrock and Kirwan, 2000). The resulting technique is a multifaceted framework comprising several taxonomies or guideword lists. The taxonomies cover both the context of the errors, and the details of the errors themselves. Figure 1, below describes the structure of the TRACEr technique. This structure has been adopted to ensure that we gather information on what happened (the context), why it happened (the root cause of the error) and how to mitigate against it (a combination of both context and error classification).

Figure 1 – Structure of the TRACEr Technique



Contextual factors describe the task that failed, the 'subject matter' of the error (e.g. a Flight Level, heading or callsign) and any factors that influenced the occurrence of the errors (Performance Shaping Factors or PSFs). The error is described in a number of ways, from its external manifestation to its internal psychological origins.

Furthermore, error detection and error recovery can be classified. Each taxonomy is further described in the following text.

Contextual Taxonomies

The **task taxonomy** is a contextual taxonomy that describes the task that failed. Examples include radar monitoring errors and strip handling errors. The **information taxonomy** describes the topic of the error or the information that was the subject of the error, e.g. flight level or heading. This is an important contextual taxonomy since it highlights practical areas for error reduction. However, few comparable taxonomies exist in other HEI tools. This is probably because of the difficulty in capturing the relevant contextual information factors in changing operational environments. However, it is of little use to know that a large number of memory failures occur if one cannot pinpoint what information is being forgotten, or alternatively what is being misperceived or misjudged. The **PSF taxonomy** classifies factors that have influenced or could influence the controller's performance negatively, aggravating the occurrence of errors. This has yielded the following major categories, each of which contains several PSF:

- **Traffic and airspace** - e.g. Traffic Complexity
- **Pilot-controller communications** - e.g. Pilot RT standards
- **Procedures** - e.g. Duration in use or Stability
- **Training and experience** - e.g. Task Familiarity
- **Workplace design, HMI, equipment factors** - e.g. Console Ergonomics
- **Ambient environment** - e.g. Noise and Distractions
- **Personal factors** - e.g. Anxiety/Panic
- **Team factors** - e.g. Handover/Takeover
- **Organisational factors** - e.g. Relations with Management

Error classification

Errors can be classified at a number of hierarchical 'levels' within TRACEr. **External Error Modes (EEMs)** classify the external and observable manifestation of the actual or potential error. EEMs are context-free and independent of cognitive processes and states (e.g. intention). They are more useful for predictive use, and provide criteria for classifying an action as an error in the first instance. Examples include 'omission', ‘action too late’, and ‘right action on wrong object'. **Cognitive Domains** describe the stage of cognitive processing that failed. The cognitive domains within TRACEr are based on a simple framework, adapted from Wickens (1992), comprising:

- **Perception** - errors in visual detection and visual search, and errors in listening.
- **Memory** - forgetting (or misrecalling) information, forgetting previous actions, and forgetting planned actions.
- **Judgement, Planning and Decision-making** - errors in judging aircraft trajectories, errors in making decisions, and errors in planning.
- **Response Execution** - actions or speech performed 'not as planned'.

This information-processing framework strikes a balance between the need for theoretical validity on the one hand, and acceptability to those with less knowledge of psychology on the other. It was borne in mind that the richest models of human performance available were of no use if target users rejected the technique on the basis that it was too complex or cumbersome. The use of a simple, familiar, generic framework avoided the prospect of invalidity caused by either changes in academic knowledge or real-world changes in air traffic management.

Within each cognitive domain, a set of **Internal Error Modes (IEMs)** describe what function of human information processing failed, and in what way it failed, within each cognitive domain. For instance, IEMs within ‘Perception and Vigilance’ include ‘late detection’, ‘misidentification’, and ‘hearback error’. **Psychological Error Mechanisms (PEMs)**, also linked to cognitive domains, describe in greater depth how the error occurred or could occur in terms of the psychological cause of the IEM, within each cognitive domain. Example PEMs within ‘Perception and Vigilance’ include ‘spatial confusion’ (confusing two visual signals in a similar spatial position or orientation) and ‘perceptual tunnelling’ (focusing on one area of the display to the exclusion of others). Hence, TRACEr describes the psychology of errors at three ‘levels’. For instance, an error may be described as a ‘perceptual error’. Going a stage further, the classification ‘mis-identification’ (an IEM) may be applied. At a ‘deeper’ level, one might find that this was due to expectations, i.e. seeing what you expect to see - ‘expectation bias’ (a PEM). This finding led to the creation and differentiation of the IEM and PEM classification systems.

The taxonomies for **Error Detection** an **Error Recovery** allows one to determine what errors are detected, by whom, by what means, and with what effect. These simple taxonomies were developed from a review of existing taxonomies (e.g. Kontogiannis, 1997, 1999; Rizzo *et al* 1995; Sellen, 1994). Table 1 below depicts the taxonomies within TRACEr.

Table 1 TRACEr taxonomies

Taxonomy	Description	Example
	CONTEXT	
Task Information	What task failed? What was the topic of the error or the information involved (e.g. what did the controller misperceive, forget, misjudge, etc.)?	Radar monitoring error Flight Level
Performance Shaping Factors	What other factors associated with the controller or the working environment affected the controller's performance?	Traffic load Noise and distractions Mode C/SSR
	ERROR	
Cognitive Domains	What cognitive domain was implicated in the error?	Perception
External Error Modes	What keyword can be applied to the error?	Omission
Internal Error Modes	What cognitive function failed, and in what way did it fail?	No identification
Psychological Error Mechanisms	How did the error occur in terms of psychological mechanisms	Perceptual Discrimination Failure
	ERROR RECOVERY	
Error Detection	How was the error detected? Who detected the error? When was the error detected?	Outcome feedback
Error Recovery	How was the error recovered? Who recovered the error? When was the error recovered? Was recovery successful?	Plan modification

TRACEr is represented as a set of decision-flow diagrams and tables to increase the usability of the technique and increase inter-analyst agreement.

The TRACEr categories ensure a structured approach to HEI, and aim to enhance the comprehensiveness, consistency, and validity of the analysis. The modular structure has several benefits. First, it allows the analyst to describe the error at a level for which there is supporting evidence. For example, if the cognitive origins of the error are unknown, the analyst can describe the external manifestations of the error. This increases the acceptability of the analysis. Second, it allows users to select only those taxonomies that are purposeful in the context of the analysis, thus increasing the efficiency of resource usage. Third, it explicitly maps the relationships between the various classifications, as opposed to a 'pick list' approach with no real 'technique'. Fourth, when strung together, the various classifications from each taxonomy form a rich picture of the context and the error. From this picture, it is then possible to derive effective error reduction measures targeted at the root cause of the error, but bearing in mind the context within which it occurs.

From TRACEr to TRACEr lite

The full version of TRACEr is aimed at a user-group of Human Factors (HF) specialists. However, in order to encourage further use of the technique by those with no formal training in HF, a reduced version of TRACEr called 'TRACEr lite' is currently being developed. The aim of this work is to reduce the overall number of categories within TRACEr for the reduced version of the technique, and to ensure that the terminology used is accepted to ATCOs, managers, designers, incident investigators and safety specialists. TRACEr lite is been developed following a number of exercises involving ATCOs, designers, and HF specialists. Initial results have led to a reduction of approximately 60% in the number IEMs (now 4 per cognitive domain on average in TRACEr lite), and 40% in the number of PEMs (now 5 per cognitive domain on average in TRACEr lite). Furthermore, the PSF list has been shortened. The whole technique is represented as decision-flow diagrams, and as a simple check-sheet for experienced users. TRACEr lite is compatible with TRACEr, such that more complex cognitive errors can be initially classified using TRACEr lite, then revisited using TRACEr by a HF specialist. The study which led to the development of TRACEr Lite will be described in full in a future paper.

The ongoing work on TRACEr involving ATCOs designers and HF specialists has also established the links between types of error (Perception - Visual; Perception - Auditory; Working Memory; Long Term Memory; Judgement, Planning & Decision Making; Response Execution - Motor; Response Execution - Speech) and the major

PSF categories. Furthermore, Error reduction advice is being developed, and linked to the TRACEr PSFs, IEMs and PEMs. This will further assist TRACEr users in selecting PSFs and formulating measures for the prevention, control or mitigation of errors.

Applying TRACEr to ATM Incidents

TRACEr has been successfully applied to a number of different forms of NATS incident reports as part of the NATS Research and Development programme over the last three years. This work has formed the basis of a new initiative to encourage the use of the technique as part of the mandatory incident analysis and investigation process within NATS.

Prior to the development of TRACEr, the incident investigation process resulted in the production of information on the primary causal factors of ATC incidents. Such investigations provide a great deal of data about what happened, but less information about why these incidents occurred. In some cases, for example when a key piece of equipment failed, it is fairly easy to determine why the event occurred. However, more often than not the event occurred because of a failure of some aspect of the controller's cognitive processing, which is much more difficult to determine from a factual report of the incident.

TRACEr provides the means to decompose an incident into its constituent errors, and further supports the decomposition of these errors to determine their underlying psychological causes. This allows us to determine why the errors occurred, and thus allows us to develop error reduction measures aimed at the cause of the error, rather than its symptoms.

The benefits of applying TRACEr to incidents is best illustrated by example. Suppose an incident occurred in which two aircraft on gradually converging headings, at the same altitude, were allowed to come within 4 miles of each other, thus breaching standard separation minima. Suppose also that the incident report indicated that the controller responsible for these aircraft had misjudged their trajectories. Without an analysis of why the error of judgement had occurred, one possible means of preventing future incidents of the same type may be to provide a support tool which provides the controller with additional information on aircraft trajectories. This would be analogous to a doctor prescribing headache pills for a patient who complains of persistent headaches. Suppose, then, that TRACEr is applied to his incident and that the results indicate that the trajectories of the two aircraft were misjudged because the amount of information displayed to controller was too great for them to process in a timely and effective manner (i.e. stimulus overload). If this were the case, then providing additional information on aircraft trajectories would not solve the problem, some means of filtering information would be the preferred solution. Taking our medical analogy one step further, TRACEr can be likened to a brain scan, that revealed that the headache was the result of a brain tumour requiring more radical intervention than headache pills.

The results of TRACEr analyses can be used in two ways. Firstly, trends in the occurrence of human error are tracked and, when error reduction measures can be derived as a direct result of the analyses, these are fed back to ATC for consideration. For example, in a previous analysis it was found that a disproportionate number of incidents were occurring within 10 minutes of position handover (where one controller is taking over a sector from another to allow for rest breaks). Further investigation revealed that in such cases, the briefing given by the off-going controller on the traffic situation did not always include all of the pertinent information. This finding resulted in the development of a simple checklist for use at position handover, which is currently under trial within NATS. Validation of this checklist will be conducted this year, using 12 months worth of incident reports covering 6 months prior to introduction of the checklist and 6 months after.

The second use of TRACEr results is the identification of weaknesses in our defences against error within the ATM system. This application requires the population of a model of the ATM system with historical error data in order to identify the areas of the system which bear the greatest risks, and thus prioritise our error reduction and prevention strategies for the future. To enable NATS to use the results of TRACEr analyses in this way, Det Norske Veritas (DNV) were commissioned to build a model of the ATM system, which could be populated and used as a high-level risk communication tool. The following section describes this model.

The ATM Safety Model

Background

In order to enhance further the safety of ATM National Air Traffic Services Ltd. commissioned DNV to assist in the development of a safety model. The intention of the model was to highlight the significant systems and interactions that maintain safety within ATM. It was also specified that the model should allow analysis of how such systems can fail, independently or in combination, leading to serious losses of separation between aircraft. A significant number of losses of separation have been attributed to human error, and therefore consideration of the way in which ATM systems can fail requires a strong emphasis on the human element of the system. To this end, the ATM Safety Model was developed with reference to human error modes, and errors that occur as a result of the interaction between the operator and the equipment.

Overview of Model

The overall model structure has five main modules (see Figure 2):

1. **Initiating Events Module** - this allows analysis of the causes and frequency of initiating events, which could lead to loss of separation. Methods used in this module to identify and represent failures and combinations of failures include fault tree analysis and historical experience.
2. **Grouping Module** - an optional module in which initiating events with similar properties could be grouped in an appropriate manner.
3. **Geometry Module** - for appropriate encounter types, various approaches are available to estimate the chance of a serious loss of separation or a collision occurring based on geometrical considerations.
4. **Detection and Resolution Module** - in which detection and resolution of imminent losses of separation are analysed. An event tree structure is proposed for clarity and for explicit modelling of the time progression of events. Key current safety nets include intervention by ATCOs, STCA, TCAS and "See and avoid" action. It should be noted that these systems will not necessarily be applied in a neat time order as implied.

5. **Dependency/ Interactions Module** - in which the impact of discrete failures on multiple safety nets can be investigated.

Modules 1 and 4 have been expanded to further levels of detail using fault and event trees. Module 5 has been analysed with a Dependency/ Interactions matrix. Modules 2 and 3 have not been addressed in this preliminary development.

Initiating Events

It was important that the overall ATM safety model shows the mechanisms by which potential losses of separation can arise. Within these mechanisms, ATM system failures can act as causes of events. A thorough investigation of the causes of initiating events is an important part of identifying both risk drivers and fruitful areas for practicable risk reduction.

The main causes can be broadly split into the following categories (Figure 3):

- ATC error;
- Pilot error;
- ATC-pilot miscommunication;
- Technical faults; and
- External factors.

Figure 3 shows a "Level 1" representation with these categories feeding into the top event of "Potential loss of separation" via an "OR" gate. Any one of these categories can lead to the top event. However, it should be noted that combinations of factors within these five categories can also lead to the top event. The "OR" gate is used for clarity in this high-level representation.

Each of the contributors shown in Figure 3 have been analysed to a further level of detail. Figure 4 presents a Level 2 representation of "ATCO Lapse". Historically these have generally been in the form of failing to take account of an aircraft at an intermediate level when providing a clearance for another aircraft's climb/descent, or misjudging the resulting separation. Another important cause is an ATCO intending to separate later, but subsequently becoming distracted.

Having developed the basic structure for these trees, they were then populated using Aircraft Proximity (AIRPROX) data. The boxes highlighted in yellow indicate the areas which have contributed most to the total number of AIRPROXs. This representation then shows the most promising areas for risk reducing measures.

Conflict Detection and Resolution

The overall detection and resolution process is represented within an event tree format. Key advantages of an event tree are its clarity (aids risk communication) and the facility to model explicitly the time progression of events. At each event tree node a fault tree has been developed to show the possible failures and combinations of factors that could cause failure of the relevant element of the detection/ resolution process.

Figure 5 shows the event tree structure in simplified form at Level 1:

1. **ATCO detects conflict** - this node evaluates the probability of the ATCO detecting the conflict before the STCA alerts. Detection needs to be "in time", i.e. allowing sufficient time for resolution and pilot reaction/manoeuvring time.
2. **ATCO resolves correctly (1)** - having detected the conflict successfully, this node evaluates the probability of the ATCO resolving the conflict "in time", i.e. allowing sufficient time for pilot reaction/manoeuvring time.
3. **Pilot reacts in time (1)** - given that the ATCO has detected the conflict and issued resolution instructions, this node evaluates the probability that the pilot ("pilots" if both aircraft have been issued instructions) reacts and manoeuvres the aircraft away from a collision course.

If the first three stages of the tree are successful and enough time is available the outcome will be "No loss of separation". However, if there are failures or delays in one or more of these stages, there is the possibility of a loss of separation or a collision.

1. **STCA alerts ATCO** - if any the first 3 stages fail, STCA should alert the ATCO to an impending collision. This node evaluates the probability that STCA is successful in achieving this "in time", i.e. allowing sufficient time for resolution and pilot reaction/manoeuvring time.
2. **ATCO resolves correctly (2)** - if STCA is successful, the ATCO then needs to resolve correctly. This will depend on similar factors as govern "ATCO resolves

correctly (1)". However, there will be less time to resolve and this may affect the probabilities of success.

3. **Pilot reacts in time (2)** - given successful STCA operation and ATCO successfully providing resolution instructions, the pilot needs to react and manoeuvre the aircraft in a timely manner. This will depend on similar factors as govern "Pilot reacts in time (1)". However, as with resolution by ATCO, there will be less time to react and this may affect the success probabilities.

If stages 4-6 of the tree are successful the outcome will not be "Collision" although a loss of separation could occur.

1. **TCAS alerts and pilot reacts in time** - in the event of failure of detection (by the ATCO and STCA), inadequate resolution by ATCO or inadequate pilot reaction following ATCO instruction, the next safety net is TCAS. This node evaluates the probability that TCAS successfully alerts the pilot(s) and that the pilot(s) manoeuvre the aircraft way from a collision course. If this is successful, the outcome will be "No collision".
2. **See and avoid successful** - if TCAS also fails the final safety net is "See and avoid", i.e. one or more pilots see the approaching aircraft and take successful evasive action.

As with the analysis of Initiating Events, Level 2 trees have been developed for each node of the event tree. Figure 6 shows an example tree for the ways in which STCA could fail.

Prioritisation of Future Safety Initiatives

By populating the model with error data from incident reports it is possible to highlight the key risk areas within the ATM system. Once these key risk areas have been identified, it is then possible to determine to what extent they will be mitigated against by future systems already under development. This process allows us to determine which risks will remain unaddressed, and therefore where to focus our efforts to develop safety nets to maintain safety within ATM. The following sections describe the outcomes of a recent pilot study conducted to determine the effectiveness of this approach, firstly to determine to what extent our future systems will mitigate key risks, and secondly to determine directions for future research to develop new safety nets.

This process also highlighted the need for research and development to maintain safety levels in the period during which development of future systems will take place. Some of the systems which demonstrate benefits for the maintenance of safety levels will not be in place for five years or more, and therefore interim measures will be required.

Future Systems

A number of new systems are being developed that will soon be deployed in the UK and the rest of Europe. One example is the Future Areas Control Tool Set (FACTS) which is being developed at ATMDC. This tool set is primarily being developed as a capacity enhancement tool; however, it is likely to have multiple safety benefits as well. The fundamental (or information) tools that underlie FACTS are:

1. **Trajectory prediction** - based on the ATCO taking no action.
2. **Medium Term Conflict Detection (MTCD)** - using the trajectory prediction aircraft pairs are identified which within the medium term will be well separated, closely separated or which will breach minimum separation. This helps the ATCO to prioritise aircraft pairs.

These tools are supported by a number of display (or Human Machine Interface, HMI) tools with which the controller will interact, either to obtain information or to enter instructions and clearances.

Together, the FACTS tools will enable the predicted separation between aircraft to be assessed easily, and changes in future separation to be monitored. The co-ordination facilities will provide greater flexibility and reduce the reliance on verbal communication between sectors. By allowing all traffic to be taken into account, there will be an increased likelihood of co-ordination offers being accepted first time. Planner controllers will be able to resolve conflict situations before they develop, thus reducing the tactical workload. Tactical controllers will be able to maintain an awareness of the traffic situation in their area of responsibility, detect problems that require intervention, and formulate plans to resolve problems.

A high level analysis was carried out using the ATM model to analyse benefits and possible problem areas with FACTS. Figure 7 summarises the analysis with respect to ATCO lapse. The ATM model provides a concise tool for analysing and communicating information about risks and the impact of future systems.

Human Factors Research

In addition to analysing future systems, the model will also be helpful in prioritising areas where research is needed. The FACTS system described above will not be implemented in the UK for several years. Until then there is a need for research into the whole area of ATCO lapses to see if any practicable measures can be introduced to reduce their occurrence. The combination of the ATM model and the human error analysis techniques described above appears to be a fruitful framework for addressing these issues.

Future Safety Nets

A number of error types were identified which were associated with the communication process between controllers and pilots. These error types include the controller writing a clearance on the flight progress strip and then issuing a different clearance to the aircraft, or the pilot mishearing the clearance or accepting a clearance issued for another aircraft with a similar callsign. Although incidents that explicitly involved such errors are relatively infrequent, it was found that incidents involving communication errors tended to be higher risk situations than some of the more frequent error types.

The communication process currently involves the controller issuing a clearance or instruction to a pilot, the pilot reading back the clearance or instruction, and the controller checking the readback against the instruction or clearance that he or she issued. There are therefore four opportunities for errors to occur:

1. In the transmission of information from the controller to the pilot;
2. In the reception of the information by the pilot;
3. In the transmission of information from the pilot to the controller;
4. In the reception of information by the controller.

In the longer term, systems such as Mode-S (where information on the aircraft flight management system (FMS) settings will be downlinked to the controller) could be used to generate alerts if an aircraft has deviated from its clearance. However, although the transponder technology for such a system already exists, it is likely to be some time before such a system can be used as an effective safety net within the ATM arena.

In the interim, some measure is required to reduce the number of communication errors. One possibility currently under investigation is the use of voice recognition technology to check the information transmitted by the controller to the aircraft. When the New En-Route Centre (NERC) enters service at the Swanwick ATC Centre in Hampshire next year, clearances formulated by the controller will be stored electronically by the workstation, rather than being written on paper strips. A voice recognition system could be used to check the verbal transmission of information with the electronically held clearance and generate an alert if the two do not match. According to the results of our pilot study, this would significantly reduce the risk of communications errors leading to risk bearing ATC incidents.

Due to the fact that current ATC voice communications utilise VHF radio signals, it is unlikely that this technology could be used to check the readback clearance from the pilot. This is because the signal quality is variable and the system would need to be capable of recognising a multitude of different accents with varying degrees of fluency in the English language. Further studies are proposed to examine the technical feasibility of such a system, and further analyses of error types are planned using a much larger sample of incidents.

Conclusion

The primary role of human error in the occurrence of ATM incidents highlights the importance of ensuring causes and mechanisms of human error are investigated, so that effective measures can be put in place to mitigate against them. TRACEr provides NATS with the means to analyse human errors associated with incidents and to predict potential errors associated with future systems. This has helped to determine safeguards to defend the air traffic system against human error. A Safety Model of the ATM system has supported these activities, acting as a high-level risk communication tool. TRACEr and the safety model have been used synergistically, with results of TRACEr analyses populating the ATM Safety Model in order to track trends, define requirements for future research, and identify weaknesses in current and future systems that require the development of additional safety nets for NATS. This work concluded that a number of common error types would be addressed by planned future systems, but that communication errors would remain unaddressed by future developments. This has led to proposals for future research and development work to investigate the feasibility and effectiveness of using speech recognition technology to detect ATCO-generated communication errors in a timely manner.

Figure 2 - Model Overview

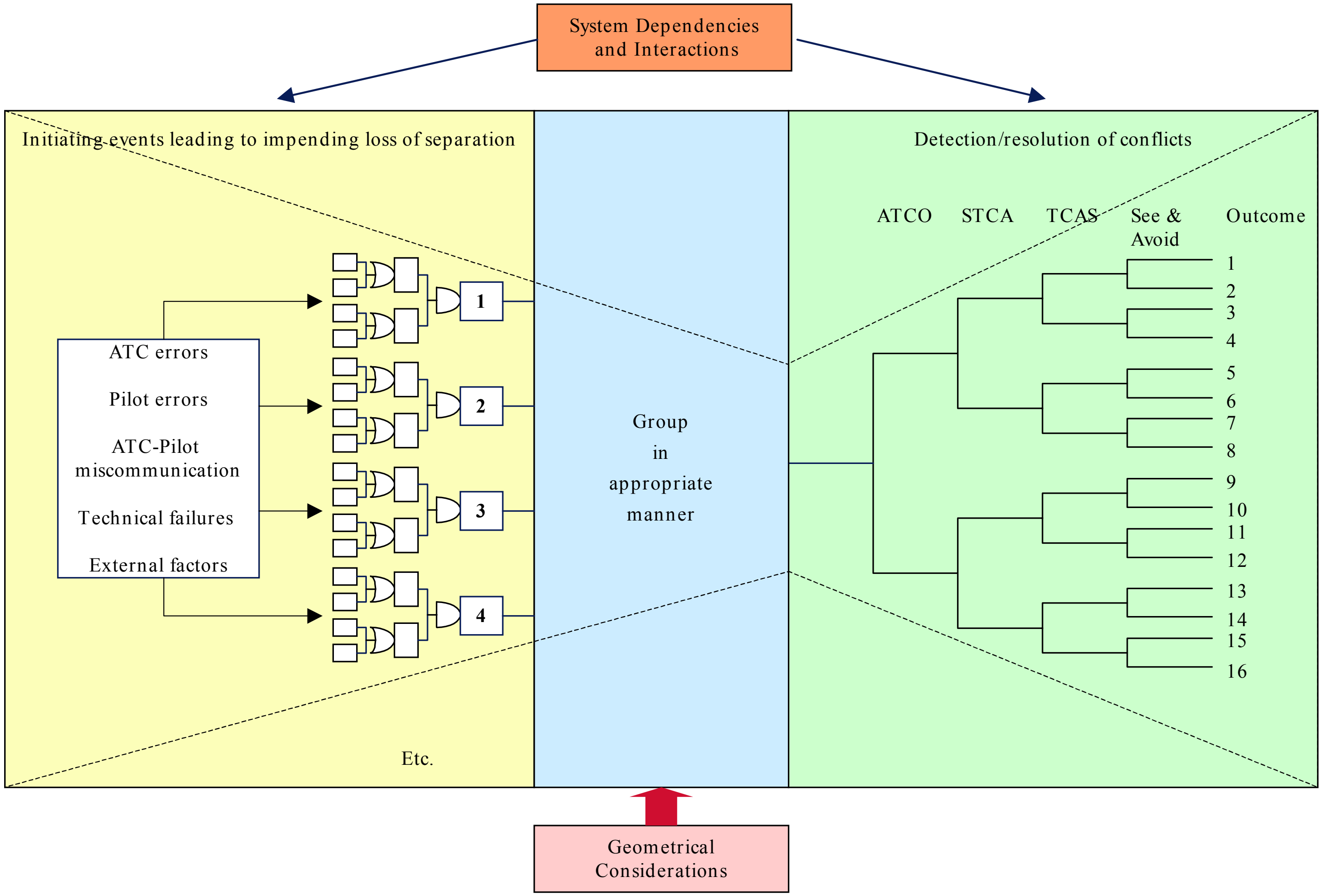


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Figure 3 - Level 1 Initiating Events

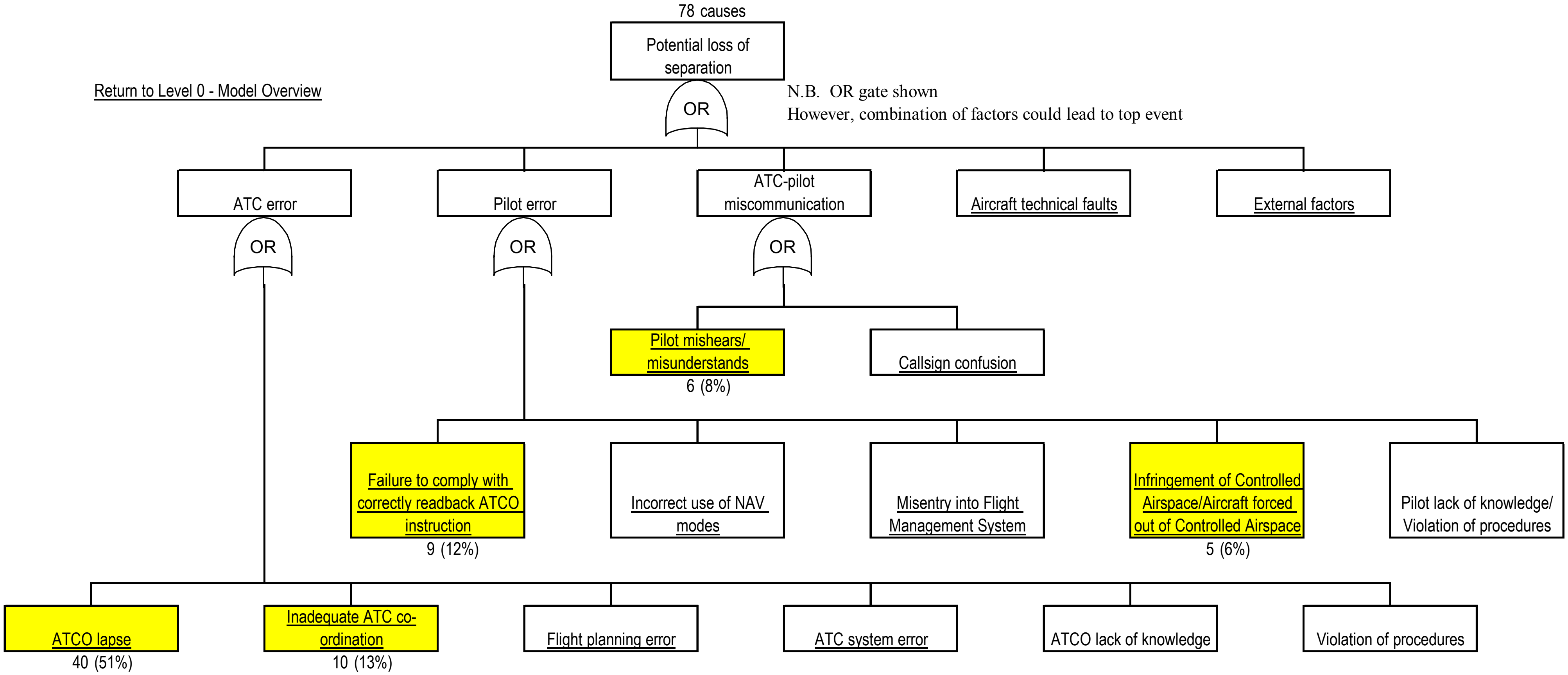

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Figure 4 - Level 2 ATCO Lapses

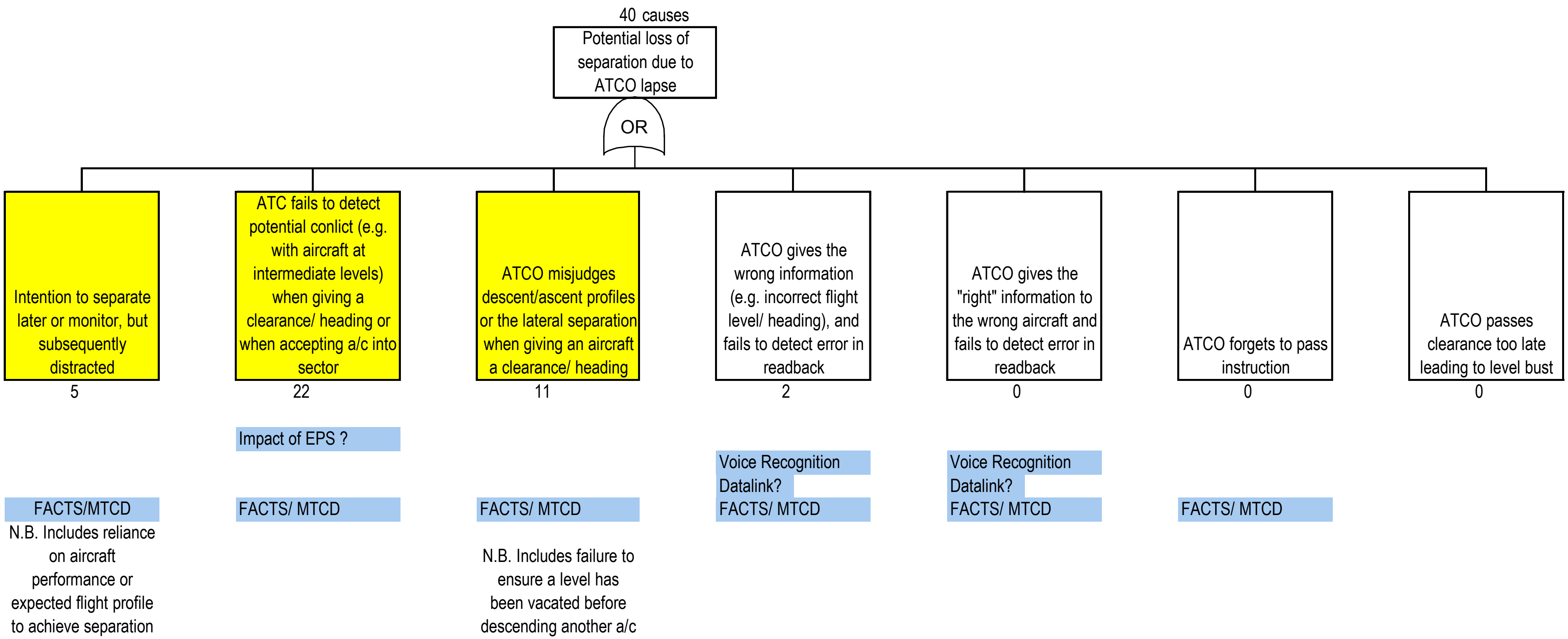

Figure 5 - Level 1 Detection and Resolution

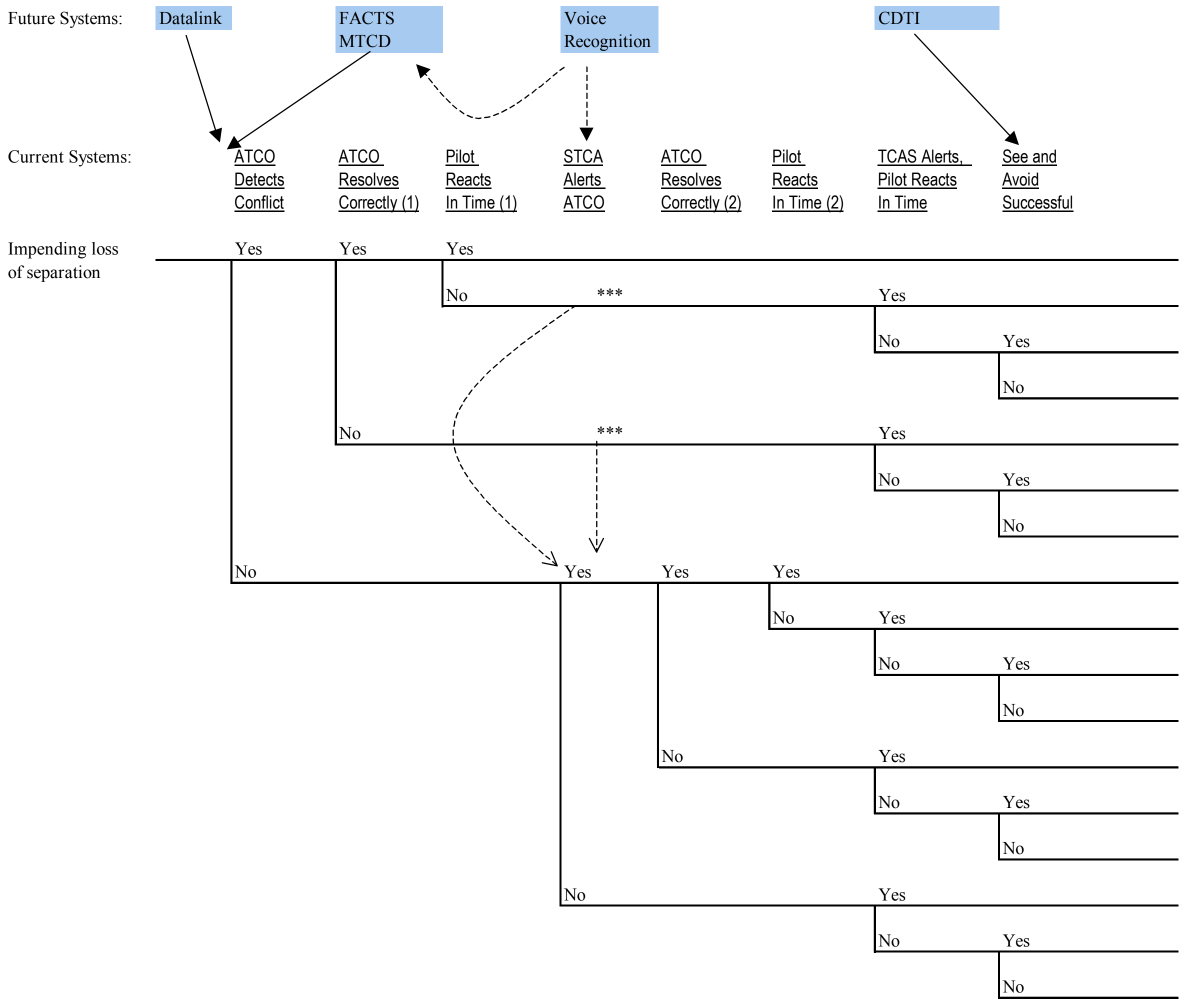

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Figure 6 - Level 2 STCA Failure

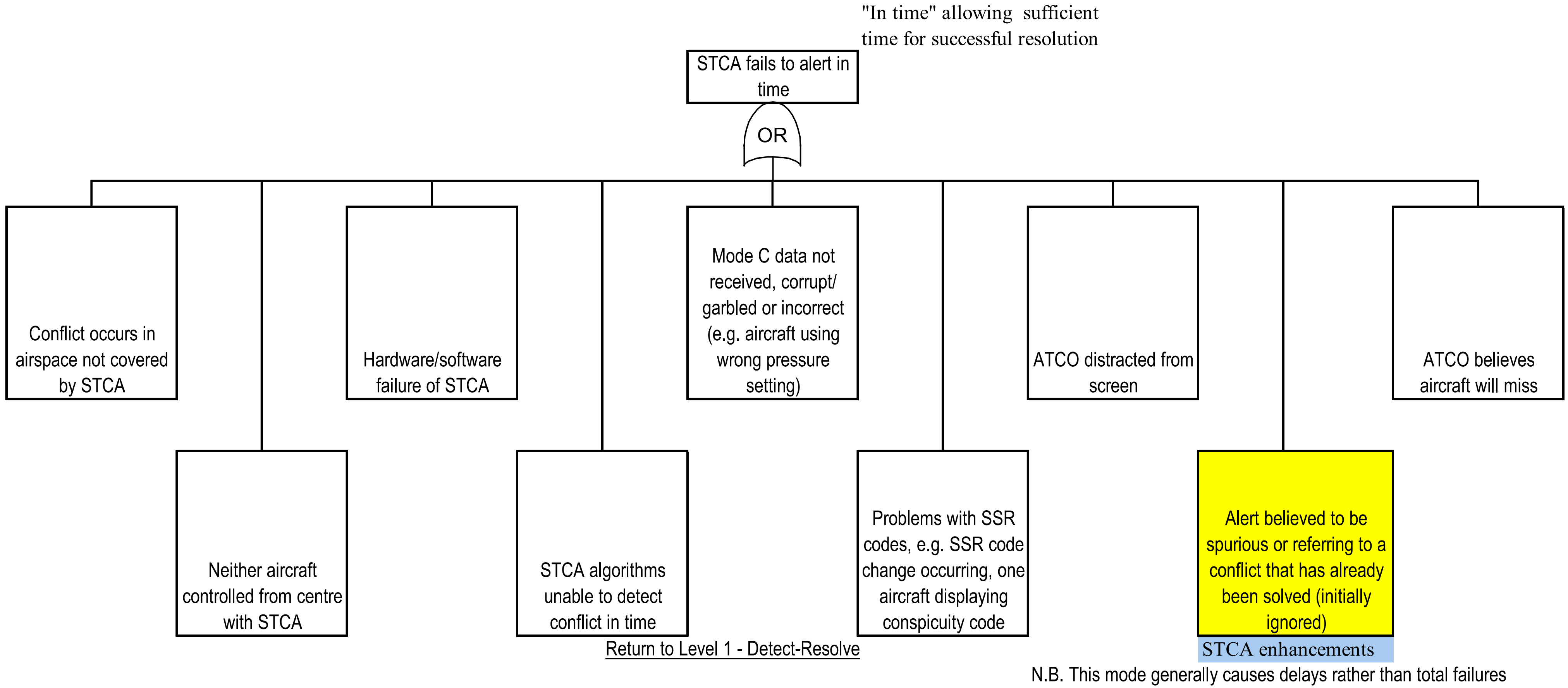
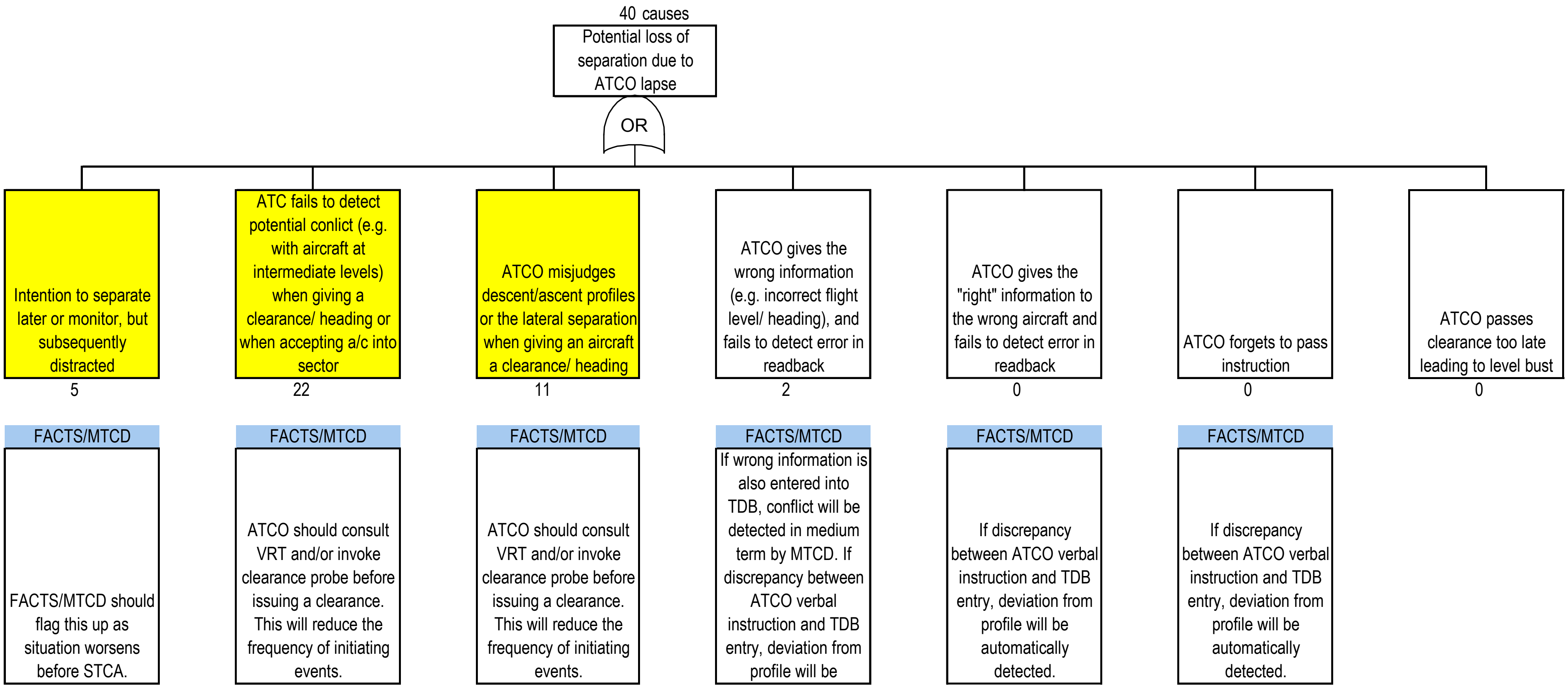


Figure 7 - Impact of Future System



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